single voxel. Test-retest measurements are a method to determine the smallest volume for which a reliable measurement can be obtained. A key asset of functional imaging is the capacity to measure physical quantities in tissue rather than contrast. In particular for longitudinal studies, monitoring treatment response, or in multi-center studies, this is critical. For radiotherapy dose painting it is necessary to know which threshold should be used to define a subvolume of the target for dose escalation. In the presentation, various quantitative methods and their reliability will be discussed.

SP-0025
Variation in DCE-MRI methodology and its implications for radiotherapy
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Dynamic contrast-enhanced magnetic resonance imaging (DCE-MRI) is a technique based on rapid acquisition of a series of images depicting the uptake of a contrast agent (CA) in tissue. Through mathematical modeling of the CA's influence on the MR signal and the distribution of CA in the tissue, physiological parameters can be obtained on a voxel by voxel level.
These parameters, which for instance reflect flow, vessel integrity, cell and vessel density, are highly relevant in cancer treatments such as radiotherapy (RT). Several studies have shown that pretreatment parameter values as well as changes during RT can be correlated with outcome. However, drawing firm conclusions on the practical value of DCE-MRI in RT is currently difficult.
The reason for this difficulty has its roots in the complexity of performing a DCE-MRI study. Obtaining accurate quantitative parameter values reflecting primarily the physiology of a tumor requires advanced imaging as well as complicated post processing. Unfortunately, even though state of the art acquisition and analysis is performed it is likely that influences from the precise acquisition settings and the analysis tools remain in the final result. Hence it is crucial that all variations during a study is minimized to maximize the sensitivity.
Not only is it of great importance to reduce the variability within a study, ideally this should also be the case between studies. But here we have a significant issue. There are a large number of unavoidable trade-offs in DCE-MRI. For instance between spatial and temporal resolution and between accuracy, complexity and robustness of the analysis. Usually each group performing a study make their own decision on where to compromise and what parameters to evaluate. Although this may be optimal in each study it is problematic when drawing conclusions on the overall value of DCE-MRI in RT.
Of this reason several authors are calling for standardization of DCE-MRI acquisition and analysis. One organization that has responded to this call is the Quantitative Imaging Biomarkers Alliance (QIBA) which has published guidelines for standardizing DCE-MRI. In a comparison of methodology in studies employing DCE-MRI in RT the results are mixed. Overall, the technical quality of studies, measured as compliance with QIBA guidelines, is improving with time. However, the spread is also increasing. Hopefully, in the future more people will adhere to the attempts to standardize DCE-MRI and thus enable more homogenous data which can be used for better answering how DCE-MRI can be employed to improve RT.

SP-0026
Importance of b-value selection and geometrical accuracy in DW-MRI for radiotherapy
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Over the last decade, Diffusion Weighted MRI(DWI) has emerged as a promising imaging technique in the field of radiation oncology.
The ability of DWI to assess a tissue's microstructure makes it potentially very valuable in tumor characterization, delineation, detection of pathological lymph nodes, response prediction and response evaluation.
However, acquisition, analysis and interpretation of the images is far from straightforward. The imaging technique is prone to distortions interfering with the accurate geometrical localisation and quantification of the tissue of interest.
Furthermore quantification is heavily influenced by the choice of machine parameters, making reproducibility an important issue.
Overcoming these problems is of the utmost importance to move DWI out of the realm of research and into daily practice.
In this talk we will identify the important parameters influencing acquisition and quantification of DWI, with emphasis on the choice of b-values and geometrical accuracy. We will discuss the implications when using DWI for extracranial radiotherapy. Finally we will look into possible solutions and provide a framework to ensure maximal exploitation of the imaging technique for the future.

Joint Symposium: ESTRO-IAEA: Joint ESTRO-IAEA efforts on dosimetry, QA and audit for advanced treatment techniques

SP-0027
New IAEA-AAPM Code of Practice for dosimetry of small photon fields used in external beam radiotherapy
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Increased use of small photon fields in stereotactic and intensity modulated radiotherapy has raised the need for standardizing the dosimetry of such fields using procedures consistent with those for conventional radiotherapy. While many problems of small field dosimetry have been raised in the past, e.g. in Report 103 of the Institute of Physics and Engineering in Medicine, a vast amount of literature has addressed most of those and solutions have been proposed for specific situations. What has hampered the development of a Code of Practice until recently was the availability of data but in the last few years a considerable number of publications have provided new data and insights that have enhanced our understanding of small field dosimetry.
An international working group, established by the International Atomic Energy Agency (IAEA) in collaboration with the American Association of Physicists in Medicine (AAPM), has finalised a Code of Practice for the dosimetry of small static photon fields. The Code of Practice consists of six chapters and two appendices. The first chapter provides an introduction to situate the distinct role of this Code of Practice as compared to previous recommendations for reference dosimetry in external beam radiotherapy. The second chapter provides a brief discussion of the physics of small photon fields with emphasis on those aspects that are relevant to understanding the concepts of the Code of Practice. Particular issues that are addressed are the definition of field size, the field size dependent response of detectors, volume averaging, fluence perturbation corrections, reference conditions and beam quality in non-conventional reference fields. The third chapter introduces all details of the formalism used, which is based on the IAEA-AAPM formalism published by Alfonso et al. (Med Phys 35:5179-5186, 2008) and is extended to clarify its application to flattening-filter-free beams (FFF beams). The fourth chapter provides a comprehensive overview of suitable dosimeters for reference dosimetry in the conventional 10 cm x 10 cm reference fields, for reference dosimetry in machine-specific reference fields at machines that cannot establish a conventional 10 cm x 10 cm reference field and for the determination of field output factors in small fields. The fifth chapter gives practical recommendations for implementing reference dosimetry in both conventional 10 cm x 10 cm

reference fields and machine-specific reference fields. The sixth chapter provides the practical recommendations for the determination of field output factors in small photon fields.
Comprehensive data on beam quality correction factors for ionization chamber types recommended for reference dosimetry are provided in chapter five and a detailed discussion on how they have been derived from the literature as well as a discussion of their uncertainties is given in the first Appendix. For beams with flattening filter (WFF beams) these data are consistent with the ones given in IAEA TRS-398 and the update to AAPM TG-51. For FFF beams additional corrections are taken into account for the difference in water to air stopping power ratios between FFF and WFF beams and for volume averaging due to the non-uniform lateral beam profiles. Comprehensive data on small field correction factors are given in chapter six for a wide range of recommended small field detectors. The second Appendix discusses in detail how these data have been compiled from the literature including both Monte Carlo calculated and experimental data and also provides a thorough evaluation of the uncertainties of those data.
The Code of Practice has been reviewed by referees selected by the AAPM and by the IAEA and is currently submitted for publication by the IAEA. This presentation is given on behalf of the IAEA-AAPM Working Group on small and non-standard field dosimetry.

SP-0028
Which dosimetric uncertainties in small fields are clinically acceptable for IMRT/VMAT?
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During the last years small field dosimetry (re-)gained importance. Several working groups highlighted its relevance in the context of high precision radiotherapy techniques. Non-conventional linear accelerators that do not support standard reference geometry and the upcoming unflattened photon beams had an impact on upcoming recommendations in this context as well. However, recent audits revealed large uncertainties in small field dosimetry with deviations up to 10% for 2 x 2 cm2 fields, which motivated the present contribution. Clinically used beam models of two TPS (Monaco, ELEKTA and iPlan, BrainLAB) were modified to mimic the large uncertainties in small field output factors. Next IMRT and VMAT treatment plans for prostate and head and neck cancer cases as well as treatment plans for stereotactic brain lesions were generated and calculated with correct and incorrect beam models, respectively. Finally, treatment plans were delivered with an ELEKTA Versa HD linac. Dose calculations were compared with measurements performed with EBT films and a detector array. Effects of uncertainties in small field output factors were less pronounced for IMRT and VMAT plans compared to stereotactic techniques delivered with static fields or dynamic arcs. TPS specific sequencing of IMRT and VMAT had an impact on the final results. The gamma evaluation performed with detector arrays was not able to dissolve uncertainties in small field dosimetry due to the rather large detector. On the other hand single detector signal was sensitive to such uncertainties. Upcoming treatment techniques like dose painting will use small fields more extensively and motivates highest accuracy in small field dosimetry. Published reference data and guidelines including detector correction factors contribute to eliminate gross uncertainties (>5%) in small field dosimetry.

SP-0029
IAEA external audits for advanced radiotherapy - lessons learnt and their relevance for industrialised countries
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The postal dose audit programme for radiotherapy dosimetry operated jointly by the International Atomic Energy Agency (IAEA) and the World Health Organization (WHO) has been in existence for over 45 years. To-date the calibration of over 11300 radiotherapy beams in 2200 hospitals in 132 countries has been audited. Several hospitals have improved their dosimetry practices over the years, and the percentage of acceptable results is > 95% at present. The IAEA records suggest that regular participation in audits is associated with higher quality dosimetry than the first participation. It confirms that the dosimetry audit is useful to enhance confidence in radiotherapy dosimetry for both medical physicists and clinicians who need assurance that their patients receive safe and high quality radiation treatment, which is not possible without accurate dosimetry. However, with the increasing complexity of radiotherapy treatments, basic dosimetry audits are no longer sufficient and more complex audit programmes testing different dosimetry parameters and treatment delivery techniques are required.
The first IAEA 'end-to-end' audit methodology was developed for 3D conformal radiotherapy. It reviewed dosimetry, imaging, treatment planning and radiotherapy delivery processes following the pathway similar to that of the patient undergoing radiotherapy. The audit was implemented at national levels with the IAEA providing an anthropomorphic thorax phantom (CIRS) and expert advice. National groups conducted the audit at local hospitals through on-site visits. TPS calculated doses were compared with ion chamber measurements for a set of test cases. In Europe, the audit has been carried out in 60 hospitals in 8 countries. About 200 data sets have been collected and reviewed. Discrepancies requiring interventions were discovered in about 10% of datasets. In addition, suboptimal beam modelling in TPSs occurred in several centres. Overall, the audit contributed to better understanding of the performance of TPSs and helped to resolve discrepancies related to imaging, dosimetry and treatment planning.
Recently, a new methodology has been developed for on-site 'end-to-end' audits to review the physics aspects of head and neck IMRT treatments. It uses a dedicated anthropomorphic head and shoulders phantom (CIRS) with a set of contours representing the target volumes and organs at risk. The contours are imported and superimposed on the CT scans of the phantom. The treatment plan is developed and transferred to the treatment machine for the dose delivery. Ion chambers and radiochromic films are used for dose measurements. Comparisons are made between the TPS calculated and measured doses. The audit methodology is currently tested within an international study group.
For >20 years the IAEA has supported the development of audit methodologies for national audit groups using remote audit tools. Current projects focus on remote IMRT audits involving different audit steps, e.g. small beam dosimetry relevant for IMRT. One study compared TPS calculated beam outputs to the published reference data sets. The results showed good agreement (within 1%) between the TPS output and the reference data for field sizes 4×4 cm2 and dose overestimation by TPSs by 2%3% for field sizes ≤ 3×3 cm2.
Auditing methodology was also developed to verify the TPS modelling of small MLC shaped beam profiles using radiochromic film measurements for 2×5 cm2 and a 2×2 cm2 fields. Relative differences between the profiles at 20%, 50% and 80% dose levels were evaluated. Only 64% beam profiles were within 3 mm agreement between the TPS calculated and film measured doses. This highlights some limitations in TPS modelling of small beam profiles in the direction of MLC leave movements. Such differences can affect patient treatments, especially for stereotactic radiotherapy and IMRT. Another study evaluated MLC performance using picket fence tests and confirmed that most MLCs performed as expected. A comparison of gamma analysis techniques was also conducted through a multicentre analysis of a film irradiated with a complex field arrangement. Differences in gamma agreement occurred that were attributed to the differences in film scanning parameters and gamma calculation algorithms. A newest study on remote 'end-to-end' IMRT audit is on-going. Overall, the results of these studies demonstrate challenges in TPS commissioning for